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P. T. S. DeVore, Y. Jiang, M. Lynch, T. Miyatake, C.
Carmona, A. C. Chan, K. Muniam, B. Jalali

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Silicon Photonics Cloud (SiCloud)

Peter T. S. DeVore^{*a,b,c}, Yunshan Jiang^a, Michael Lynch^{a,d}, Taira Miyatake^{a,e}, Christopher Carmona^b,
Andrew C. Chan^a, Kuhan Muniam^b, and Bahram Jalali^{a,f,g,h}

^aDept. of Electrical Engineering, University of California, Los Angeles, CA, USA, 90095;

^bDept. of Physics and Astronomy, University of California, Los Angeles, CA, USA, 90095;

^cCurrent Location: Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA, USA, 94550

^dDept. of Computer Science, University of California, Los Angeles, CA, USA, 90095;

^eDept. of Mechano Informatics, University of Tokyo, Tokyo, Japan;

^fCalifornia NanoSystems Institute, University of California, Los Angeles, CA, USA, 90095;

^gDept. of Bioengineering, University of California, Los Angeles, CA, USA, 90095;

^hDept. of Surgery, David Geffen School of Medicine, University of California, Los Angeles, CA, USA, 90095

*pdevore@ucla.edu

ABSTRACT

We present SiCloud (Silicon Photonics Cloud), the first free, instructional web-based research and education tool for silicon photonics. SiCloud's vision is to provide a host of instructional and research web-based tools. Such interactive learning tools enhance traditional teaching methods by extending access to a very large audience, resulting in very high impact. Interactive tools engage the brain in a way different from merely reading, and so enhance and reinforce the learning experience. Understanding silicon photonics is challenging as the topic involves a wide range of disciplines, including material science, semiconductor physics, electronics and waveguide optics. This web-based calculator is an interactive analysis tool for optical properties of silicon and related material (SiO₂, Si₃N₄, Al₂O₃, etc.). It is designed to be a one stop resource for students, researchers and design engineers. The first and most basic aspect of Silicon Photonics is the Material Parameters, which provides the foundation for the Device, Sub-System and System levels. SiCloud includes the common dielectrics and semiconductors for waveguide core, cladding, and photodetection, as well as metals for electrical contacts. SiCloud is a work in progress and its capability is being expanded. SiCloud is being developed at UCLA with funding from the National Science Foundation's Center for Integrated Access Networks (CIAN) Engineering Research Center.

Keywords: silicon photonics calculator, silicon photonics simulation, silicon photonics tool, silicon photonics cloud, silicon photonics education, silicon, fused silica, material properties, refractive index, absorption, waveguides, optical properties, visualization

1. INTRODUCTION

The silicon photonics market is expected to grow at a fast pace (38% CAGR) and reach a substantial size^{1, 2}, primarily because the demand for ever higher data bandwidths does not subject optical wires to the short maximum lengths of their electronic counterparts. To meet the silicon photonics market demand for knowledgeable and skilled engineers, silicon photonics educational resources continue to grow, evidenced by, e.g., the plethora of new books³⁻⁷ and workshops. Understanding this field is particularly challenging for researchers and students alike, as silicon photonics involves a wide range of disciplines, including material science, semiconductor physics, electronics and waveguide optics. Evidently, the process of learning silicon photonics must be as effective as possible.

*pdevore@ucla.edu

Web-based educational tools are particularly effective and efficient. Software tools catalyze learning by enhancing visibility of the process and encouraging active participation. Web-based tools in particular reach global audiences, with minimal effort per student. Pre-existing web-based photonics-related engineering tools^{8, 9} excel in their own capabilities, but none address all needs of the silicon photonics field. Here we present SiCloud (see Figure 1 and <http://www.sicloud.org/>), which is the first web-based silicon photonics tool, and is expected to jumpstart the learning process. We envision that SiCloud will become a complete silicon photonics learning platform, which will span from low-level material physics to high-level systems engineering.



Figure 1. Landing page of SiCloud, the first web-based silicon photonics calculator (<http://www.sicloud.org/>). It features tabs that cover different aspects of silicon photonics. The first tab is the Overview, giving the big picture motivation of the impact of silicon photonics, followed by a list of important books and reviews (not seen here). The second selectable tab is Material Parameters, which contains optical parameters of most important silicon photonic materials (shown later). More tabs that cover higher levels of abstraction are in progress.

2. VERSION 1.0 CAPABILITIES

SiCloud Version 1.0 was released on June 21, 2014 and demonstrated to the attendees at the NSF CIAN Annual Site Visit in Tucson, Arizona on May 14, 2014. This version contains the Material Parameters tab (c.f. Figure 2), a convenient tool for accessing and exploring key properties of many important silicon photonics materials. At the top is the Main Graph, which plots a wide variety of optical properties vs. frequency. A critical quantity of interest for these materials is their loss, as sufficient transmission of light is necessary for any optical system. Thus, below the Main Graph we have included the Loss Graph, which calculates the loss through a given length of bulk material vs. frequency.

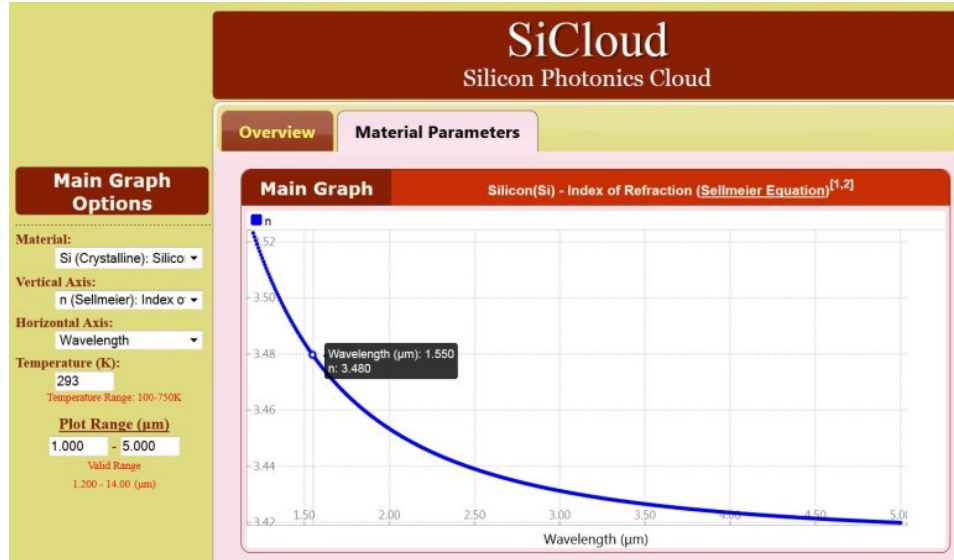


Figure 2. The Material Parameters tab features the Main Graph which displays important optical parameters vs. frequency. Data values can be seen by hovering the mouse over a given data point. One may also change the horizontal axis range (the valid range over which data is available is conveniently given), and units between Wavelength (μm) and Frequency (THz). If there is data available for different temperatures, that is also given.

2.1 Material Parameters: Main Graph

SiCloud includes data on the fundamental materials used in silicon photonics. It covers the main substrate and waveguide dielectrics (silicon, silicon nitride, silica, and sapphire), metals for optoelectronic functions (copper, tungsten and aluminum), and germanium for photodetection functionality (c.f. Figure 3). Refractive index and extinction coefficient data are provided, and the loss per unit length is also calculated. The primary waveguide material, crystalline silicon, has been well-characterized, so a variety of other useful properties are included (c.f. Figure 4). For example, silicon is a highly nonlinear optical material, and nanoscale confinement given by the typical high index contrast waveguiding further enhances the nonlinear effect. This has been exploited for a large number of applications, including continuum generation^{10, 11}, lasing in silicon^{12, 13}, all-optical switching¹⁰, and mode-locking¹⁴. Thus, we included the Kerr, Raman, and two-photon absorption coefficients.

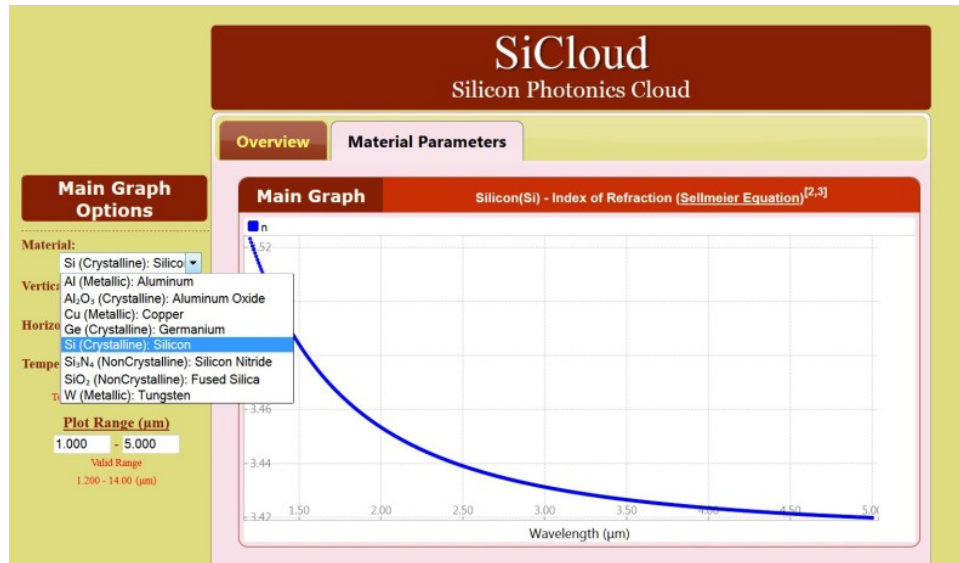


Figure 3. Main Graph on the Material Parameters tab, highlighting the available materials. Included are common waveguide dielectrics, metals for contacts and optoelectronic capabilities, and germanium for photodetection in the telecommunications band.

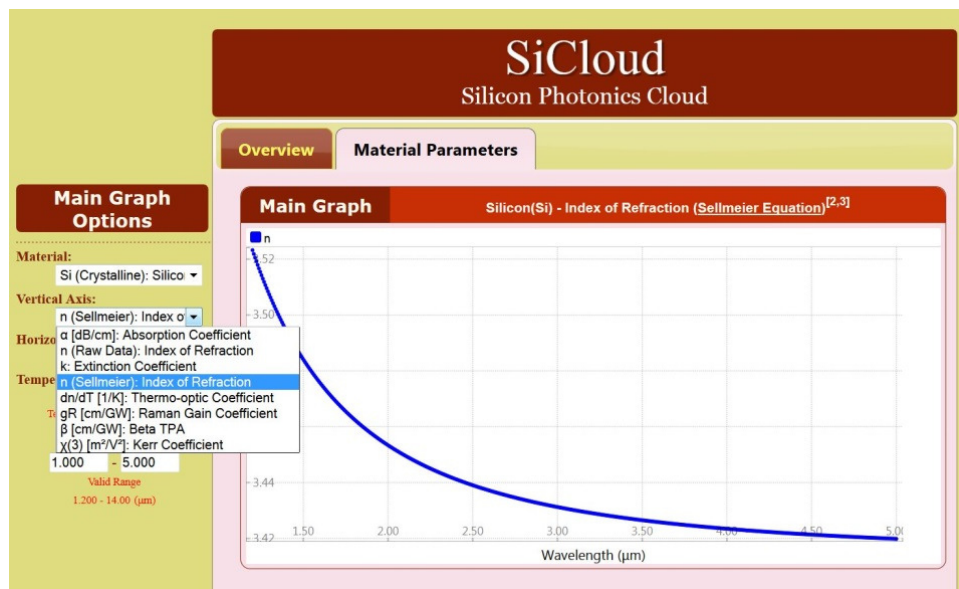


Figure 4. Vertical axis properties available to graph for silicon. SiCloud provides refractive index and absorption information for all materials included. In addition, as silicon is the most prevalent primary waveguide material, it is important to understand how it may be modulated by external effects, so nonlinear optical (Kerr, Raman, and two-photon absorption) and thermo-optic coefficients have also been included.

2.2 Material Parameters: Loss Graph

The Loss Graph, which calculates the absorption over a given length of material with and without reflections, is immediately below the Main Graph in the Material Parameters tab.

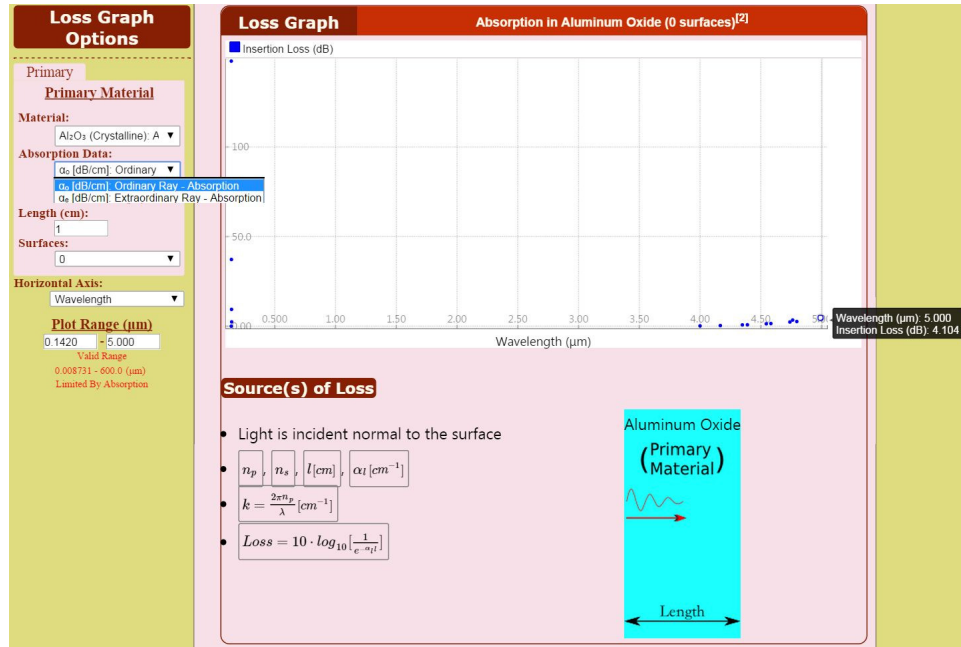


Figure 5. Loss Graph for absorption through a given material. One may select the length, as well as the number of surfaces to take into account reflections, in addition to the horizontal axis range and units. SiCloud also has available both the ordinary and extraordinary quantities, as seen here for the anisotropic material sapphire (Al_2O_3).

So that the user may independently verify data accuracy, and include citations in publications, we have provided references in the top right corner of the graph's description, as seen in Figure 6. When multiple datasets are used, multiple references are given. As both the Main Graph and Loss Graph materials may be selected separately, independent reference numbers are used as required. The Loss Graph in particular will include references for both materials used, if one includes reflection loss with multiples surfaces.

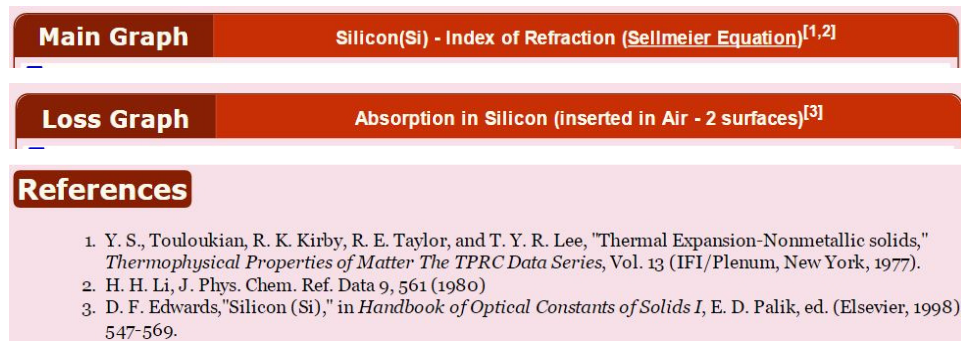


Figure 6. The Main Graph and Loss Graph include references for the data provided.

3. HISTORY

SiCloud was developed at UCLA as part of the NSF Center for Integrated Access Networks (CIAN) Engineering Research Center (ERC). It was launched at the 2014 CIAN Annual NSF Site Visit in Tucson, Arizona on May 14, 2014. Feedback was used from this meeting to improve the tool, and it debuted worldwide on June 21, 2014.

4. CONCLUSION

Here we have presented SiCloud, the first web-based silicon photonics calculator. Our vision is to provide a one-stop portal for getting started in any subfield of silicon photonics. It introduces students and researchers to the subject, and (so far) provides information on important silicon photonics material properties. With the material physics as a strong

foundation, we plan to build higher levels of abstraction up towards the sub-system and system (i.e., circuit) levels, to provide a “vertically-integrated” exploratory platform. We expect that SiCloud will help catalyze understanding silicon photonics and accelerate progress in academia and industry. Those who are interested in contributing may contact the main authors via email (but see <http://www.sicloud.org/> as contact information may change).

5. ACKNOWLEDGEMENTS

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